

## BMP-19

### BMP: RIPRAP

#### Definition

A permanent, erosion-resistant ground cover of large, loose, angular stone with filter fabric or granular underlining.

#### Purposes

1. To protect the soil from the erosive forces of concentrated runoff.
2. To slow the velocity of concentrated runoff while enhancing the potential for infiltration.
3. To stabilize slopes with seepage problems and/or non-cohesive soils.

#### Conditions Where Practice Applies

Wherever soil and water interface and the soil conditions, water turbulence and velocity, expected vegetative cover, etc., are such that the soil may erode under the design flow conditions. Riprap may be used, as appropriate, at stormdrain outlets, on channel banks and/or bottoms, roadside ditches, drop structures, at the toe of slopes, as transition from concrete channels to vegetated channels, etc.

#### Planning

##### Graded vs. Uniform Riprap-

Riprap is classified as either graded or uniform. A sample of graded riprap would contain a mixture of stones which vary in size from small to large. A sample of uniform riprap would contain stones which are all fairly close in size.

For most applications, graded riprap is preferred to uniform riprap. Graded riprap forms a flexible self-healing cover, while uniform riprap is more rigid and cannot withstand movement of the stones. Graded riprap is cheaper to install, requiring only that the stones be dumped so that they remain in a well-graded mass. Hand or mechanical placement of individual stones is limited to that necessary to achieve the proper thickness and line. Uniform riprap requires placement in a more or less uniform pattern, requiring more hand or mechanical labor.

Riprap sizes can be designed by either the diameter or the weight of the stones. It is often misleading to think of riprap in terms of diameter, since the stones should be angular instead of spherical. However, it is simpler to specify the diameter of an equivalent size of spherical stone. Table 19-1 lists some typical stones by weight, spherical diameter and the corresponding rectangular dimensions. These stone sizes are based upon an assumed specific weight of 2,645 kg/m<sup>3</sup> (165 lbs./ft<sup>3</sup>).

Since graded riprap consists of a variety of stone sizes, a method is needed to specify the size range of the mixture of stone. This is done by specifying a diameter of stone in the mixture for which some percentage, by weight, will be smaller. For example,  $d_{85}$  refers to a mixture of stones in which 85% of the stone by weight would be smaller than the diameter specified. Most designs are based on  $d_{50}$ . In other words, the design is based on the average size of stone in the mixture. Table 19-2 lists classes of standard graded riprap sizes by diameter and weight of the stone.

**TABLE 19-1  
SIZE OF RIPRAP STONES**

Weight		Mean Spherical Diameter		Angular Length		Shape: Width, Height	
Kg	lbs	m	ft	m	ft	m	ft
20	50	0.2	0.8	0.4	1.4	0.1	0.5
45	100	0.3	1.1	0.5	1.8	0.2	0.6
70	150	0.4	1.3	0.6	2.0	0.2	0.7
135	300	0.5	1.6	0.8	2.6	0.3	0.9
225	500	0.6	1.9	0.9	3.0	0.3	1.0
455	1000	0.7	2.2	1.1	3.7	0.4	1.2
680	1500	0.8	2.6	1.4	4.7	0.5	1.5
910	2000	0.9	2.8	1.6	5.4	0.5	1.8
1815	4000	1.1	3.6	1.8	6.0	0.6	2.0
2725	6000	1.2	4.0	2.1	6.9	0.7	2.3
3630	8000	1.4	4.5	2.3	7.6	0.8	2.5
9080	20000	1.8	6.1	3.0	10.0	1.0	3.3

To ensure that stone of substantial weight is used when implementing riprap structures, specified weight ranges for individual stones and composition requirements should be followed. Such guidelines will help to prevent inadequate stone from being used in construction of the measures and will promote more consistent stone classification statewide. Table 19-3 notes these requirements.

#### Sequence of Construction-

Since riprap is used where erosion potential is high, construction must be sequenced so that the riprap is put in place with the minimum possible delay. Disturbance of areas where riprap is to be placed should be undertaken only when final preparation and placement of the riprap can follow immediately behind the initial disturbance. Where riprap is used for outlet protection, the riprap should be placed before or in conjunction with the construction of the pipe or channel so that it is in place when the pipe or channel begins to operate.

#### Design Criteria

#### Gradation-

The riprap shall be composed of a well-graded mixture down to the 25 millimeter (1-inch) size particle such that 50% of the mixture by weight shall be larger than the  $d_{50}$  size as determined from the design procedure. A well-graded mixture as used herein is defined as a mixture composed primarily of the larger stone sizes but with a sufficient mixture of other sizes to fill the progressively smaller voids between the stones. The diameter of the largest stone size in such a mixture shall be 1.5 times the  $d_{50}$  size.

**TABLE 19-2  
GRADED RIPRAP - DESIGN VALUES**

Riprap Class	D <sub>15</sub> Weight		Mean D <sub>15</sub> Spherical Diameter		Mean D <sub>50</sub> Spherical Diameter	
	Kg	lbs	m	ft	m	ft
Class A1	11	25	0.2	0.7	0.3	0.9
Class I	23	50	0.2	0.8	0.3	1.1
Class II	68	150	0.4	1.3	0.5	1.6
Class III	227	500	0.6	1.9	0.7	2.2
Type I	680	1,500	0.8	2.6	0.9	2.8
Type II	2,725	6,000	1.2	4.0	1.4	4.5

The designer, after determining the riprap size that will be stable under the flow conditions, shall consider that size to be a minimum size and then, based on riprap gradations actually available in the area, select the size or sizes that equal or exceed the minimum size. The possibility of damage by children shall be considered in selecting a riprap size, especially if there is nearby water or a gully in which to toss the stones.

#### Thickness-

The minimum thickness of the riprap layer shall be 2 times the maximum stone diameter, but not less than 150 millimeters (6 inches).

#### Quality of Stone-

Stone for riprap shall consist of field stone or rough unhewn quarry stone of approximately rectangular shape. The stone shall be hard and angular and of such quality that it will not disintegrate on exposure to water or weathering and it shall be suitable in all respects for the purpose intended. The specific gravity of the individual stones shall be at least 2.5.

Rubble concrete may be used provided it has a density of at least 2,400 kilograms per cubic meter (150 pounds per cubic foot), and otherwise meets the requirement of this Best Management Practice.

**TABLE 19-3  
GRADED RIPRAP - WEIGHT ANALYSIS**

Riprap Class/Type	Weight Range*	Requirements for Stone Mixture
Class A1	11-34 kg (25-75 lbs)	Max. 10% > 34 kg (Max. 10% > 75 lbs)
Class I	23-68 kg (50-150 lbs)	60% > 45 kg (60% > 100 lbs)
Class II	68-227 kg (150-500 lbs)	50% > 136 kg (50% > 300 lbs)
Class III	227- 681 kg (500-1,500 lbs)	50% > 409 kg (50% > 900 lbs)
Type I	681-1,816 kg (1,500-4,000 lbs)	Av. wt. = 908 kg (Av. wt. = 2,000 lbs.)
Type II	2,724- 9,080 kg (6,000-20,000 lbs)	Av. wt. = 3,632 kg (Av. wt. = 8,000 lbs.)
*In all classes/types of riprap, a maximum 10% of the stone in the mixture may weigh less than the lower end of the range.		

#### Filter Fabric Underlining-

A lining of engineering filter fabric (geotextile) shall be placed between the riprap and the underlying soil surface to prevent soil movement into or through the riprap. Table 19-4 notes the minimum physical properties of the filter fabric.

Filter fabric shall not be used on slopes greater than 1.5:1 as slippage may occur and should be used in conjunction with a layer of coarse aggregate (granular filter blanket is described below) when the riprap to be placed is Class II or larger.

#### Granular Filter-

Although the filter cloth underlining or bedding is the preferred method of installation, a granular (stone) bedding is a viable option when the following relationship exists:

$$\frac{d_{15}filter}{d_{85}base} < 5 < \frac{d_{15}filter}{d_{15}base} < 40$$

and,

$$\frac{d_{50}filter}{d_{50}base} < 40$$

In these relationships, filter refers to the overlying material and base refers to the underlying material. The relationships must hold between the filter material and the base material and between the riprap and the filter material. In some cases, more than one layer of filter material may be needed. Each layer of filter material should be approximately 150 millimeters (6-inches) thick.

#### Riprap at Outlets-

Design criteria for sizing the stone and determining the dimensions of riprap pads used at the outlet of drainage structure are contained in OUTLET PROTECTION (BMP-18). A filter fabric underlining is required for riprap used as outlet protection.

**TABLE 19-4**  
**REQUIREMENTS FOR FILTER FABRIC USED WITH RIPRAP**

Physical Property	Test Method	Requirements
Equivalent Opening Size	Corps of Engineers CWO 2215-77	Equal or greater than U.S. No. 50 sieve
Tensile Strength* @ 20% (maximum) in.)	VTM-52	0.5 kg/linear millimeter (30 lbs./linear  minimum
Puncture Strength	ASTM D751*	36 kg (80 lbs) (minimum)

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\* Tension testing machine with ring clamp, steel ball replaced with 7.9 millimeter (5/16 inch) diameter solid steel cylinder with hemispherical tip centered within the ring clamp.

Seams shall be equal in strength to basic material.

Additional fabric material or non-corrosive steel wire may be incorporated into the fabric to increase overall strength.

#### Riprap for Channel Stabilization-

Riprap for channel stabilization shall be designed to be stable for the condition of bank-full flow in the reach of channel being stabilized. This method establishes the stability of the rock material relative to the forces exerted upon it.

Riprap shall extend up the banks of the channel to a height equal to the maximum depth of flow or to a point where vegetation can be established to adequately protect the channel.

The riprap size to be used in a channel bend shall extend upstream from the point of curvature and downstream from the bottom of the channel to a minimum depth equal to the thickness of the blanket and shall extend across the bottom of the channel the same distance (see Figure 19-1).

### Freeboard and Height of Bank-

For riprapped and other lined channels, the height of channel lining above the water surface should be based on the size of the channel, the flow velocity, the curvature, inflows, wind action, flow regulation, etc.

The height of the bank above the water surface varies in a similar manner, depending on the above factors plus the type of soil.

Figure 19-2 is based on information developed by the U.S. Bureau of Reclamation for average freeboard and bank height in relation to channel capacity. This chart should be used by the designer to obtain a minimum freeboard for placement of riprap and top of bank.

### Riprap for Slope Stabilization-

Riprap for slope stabilization shall be designed so that the natural angle of repose of the stone mixture is greater than the gradient of the slope being stabilized (see Figure 19-3).

### Riprap for Lakes and Ponds Subject to Wave Action-

Riprap used for shoreline protection on lakes and ponds may be subject to wave action. The waves affecting the shoreline may be wind-driven or created by boat wakes.

### Riprap for Installations Subject to Tidal and Wave Action-

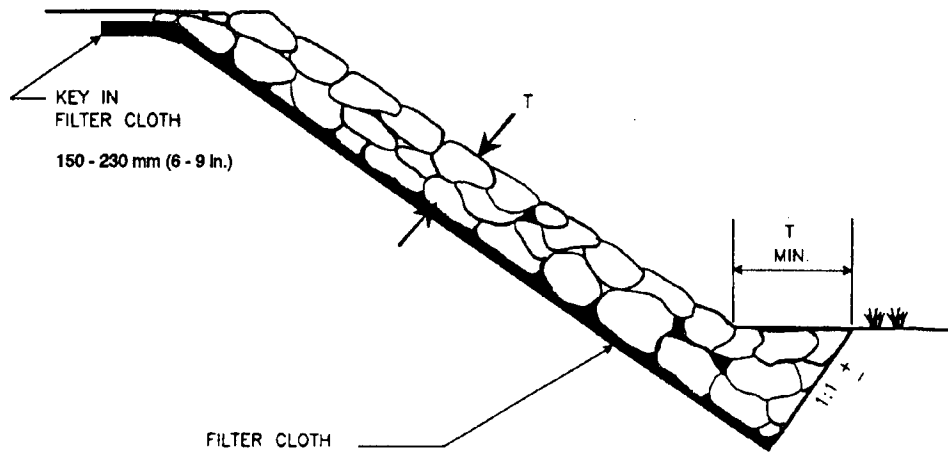
A riprap design for shoreline protection in tidal areas must meet all applicable state and federal requirements and should be carried out by a qualified professional.

### Construction Specifications

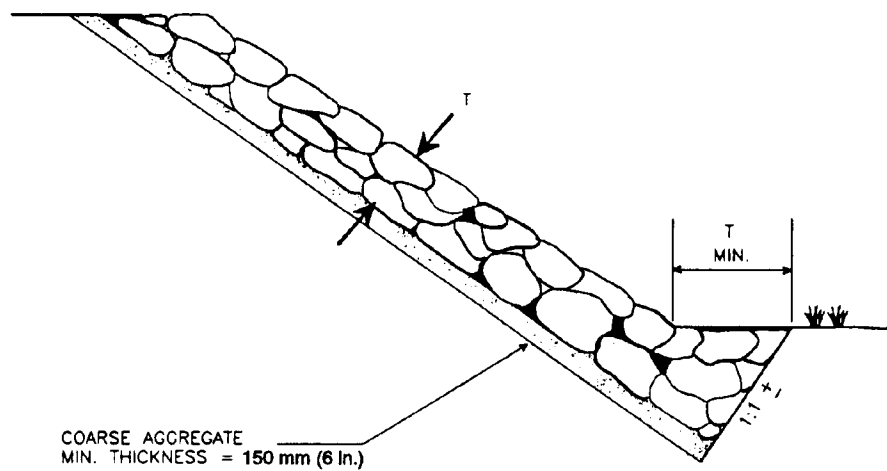
**Subgrade Preparation:** The subgrade for the riprap or filter shall be prepared to the required lines and grades. Any fill required in the subgrade shall be compacted to a density approximately that of the surrounding undisturbed material. Brush, trees, stumps and other objectionable material shall be removed.

**FIGURE 19-1: TOE REQUIREMENTS FOR  
BANK STABILIZATION**

FILTER CLOTH UNDERLINER (PREFERRED)

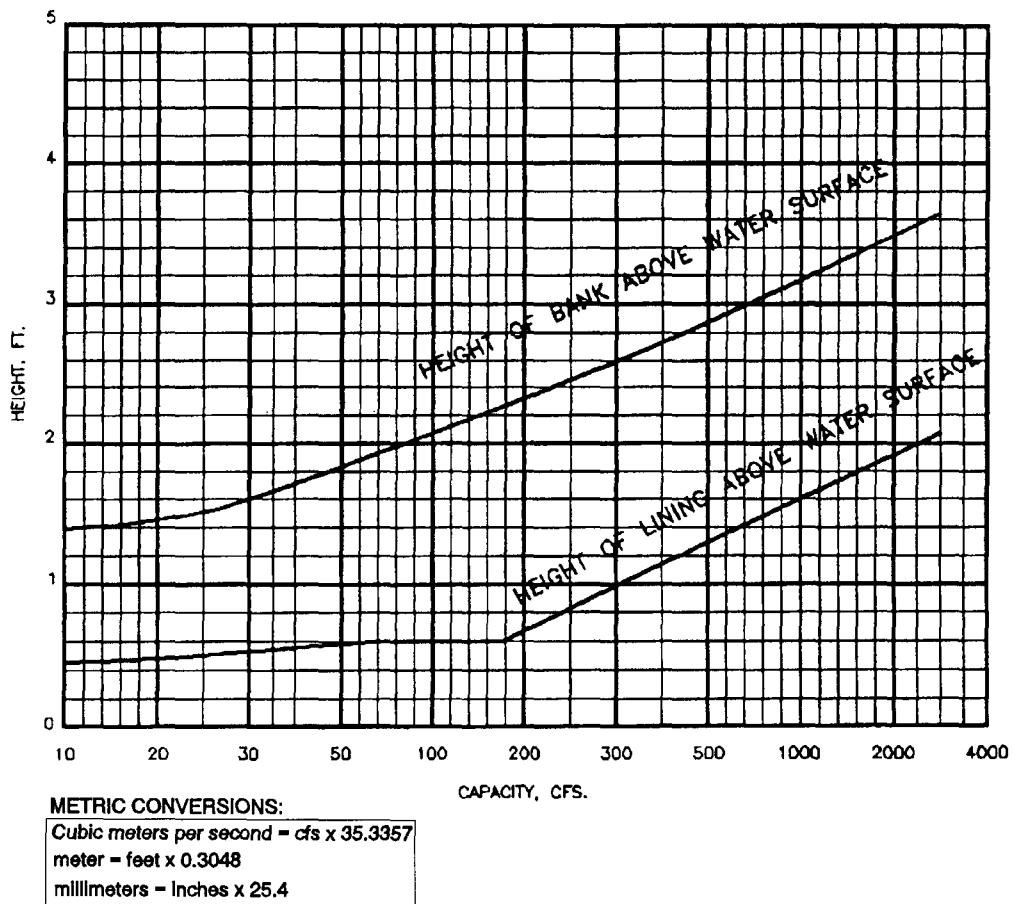


GRANULAR FILTER

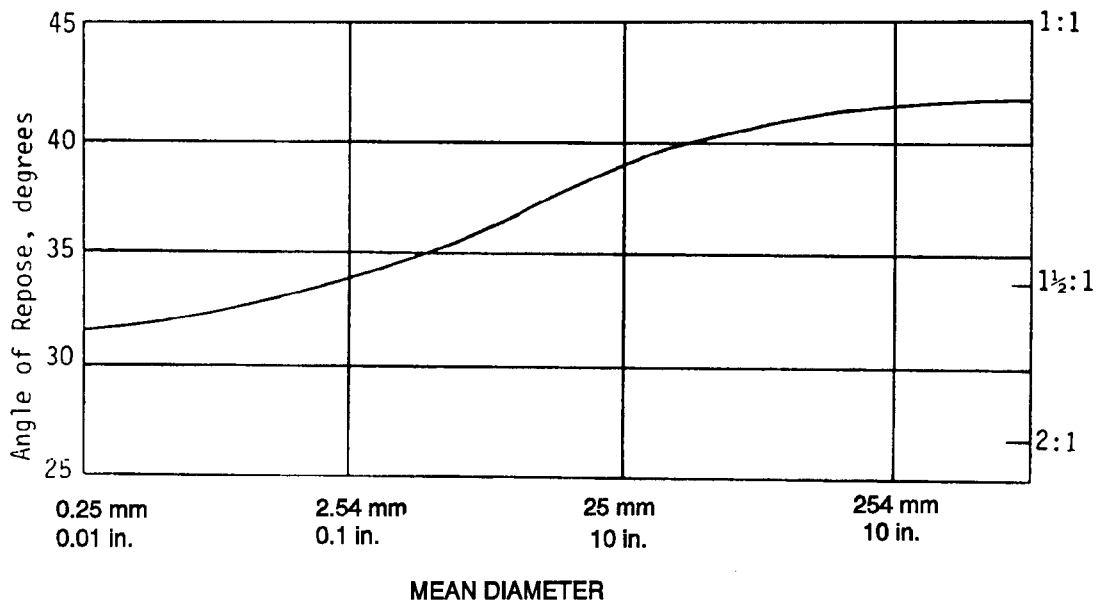




**FIGURE 19-2: RECOMMENDED FREEBOARD AND  
HEIGHT OF BANK OF LINED CHANNELS**



**FIGURE 19-3: ANGLE OF REPOSE FOR RIPRAP STONES**



**Filter Fabric or Granular Filter:** Placement of the filter fabric should be done immediately after slope preparation. For granular filters, the stone should be spread in a uniform layer to the specified depth, normally 150 millimeters (6 inches). Where more than one layer of filter material is used, the layer should be spread so that there is minimal mixing of the layers.

When installing geotextile filter cloths, the cloth should be placed directly on the prepared slope. The edges of the sheets should overlap by at least 300 millimeters (12 inches). Anchor pins, 400 millimeters (15 inches) long, should be spaced every meter (3 feet) along the overlap. The upper and lower ends of the cloth should be buried at least 300 millimeters. Care should be taken not to damage the cloth when placing the riprap. If damage occurs, that sheet should be removed and replaced. For large stone (Class II or greater), a 150 millimeter (6-inch) layer of granular filter will be necessary to prevent damage to the cloth.

**Stone Placement:** Placement of riprap should follow immediately after placement of the filter. The riprap should be placed so that it produces a dense well-graded mass of stone with a minimum of voids. The desired distribution of stones throughout the mass may be obtained by selective loading at the quarry, controlled dumping of successive loads during final placing, or by a combination of these methods. The riprap should be placed to its full thickness in one operation. The riprap should not be placed in layers. The riprap should not be placed by dumping into chutes or

similar methods which are likely to cause segregation of the various stone sizes. Care should be taken not to dislodge the underlying material when placing the stones.

The finished slope should be free of pockets of small stone or clusters of large stones. Hand placing may be necessary to achieve the required grades and a good distribution of stone sizes. Final thickness of the riprap blanket should be within plus or minus 1/4 of the specified thickness.

### Maintenance

Once a riprap installation has been completed, it should require very little maintenance. It should, however, be inspected periodically to determine if high flows have caused scour beneath the riprap or filter fabric or dislodged any of the stone. Care must be taken to properly control sediment-laden construction runoff which may drain to the point of the new installation. If repairs are needed, they should be accomplished immediately.